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SUMMARIES OF HIGH TEMPERATURE SUPERCONDUCTOR PRESENTATIONS AT A MEETING OF THE CANADIAN ASSOCIATION OF PHYSICISTS

I. Balbaa, F.Y. Chu, M.A. Green
P. Kirkby and L. Mannik

At the recent Canadian Association of Physicists meeting, 20 invited and contributed papers on high temperature superconductivity were presented. No breakthroughs of transition temperatures or critical current densities were reported. Most presentations dealt with material characteristics and experiments to verify various hypotheses of superconducting mechanisms. This report summarizes the highlights of the presentations.

INTRODUCTION

High temperature superconductivity (HTSC) was the focus of discussion during the recent Canadian Association of Physicists (CAP) meeting at the University of Toronto. Twenty invited and contributed papers on HTSC were presented during various sessions which attracted huge audiences (Appendix 1). At the invited paper session, which featured prominent researchers from AT&T, Argonne National Laboratory, Princeton and McMaster, over 400 physicists attended. The authors attended the three HTSC sessions (including an evening session) and the highlights are summarized in this report.

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GENERAL REMARKS

Summaries of the HTSC invited paper session, contributed paper session (Monday evening), and the Industrial Material Session are contained in Appendices 2, 3 and 4. Some of the technical highlights are:

- Presenters were very cautious about transition temperatures. All presentations dealt with only two types of materials, 40 K (LaSrCuO) and 90 K (YBaCuO) oxides.

- The scientists have employed various sophisticated techniques to determine the structure responsible for the superconducting phase. For the 40 K and 90 K materials, the properties and structures appeared to be well-defined. The key elements are the copper and oxygen atoms while the barium and rare earth elements played a minor role.

- The actual superconducting mechanism still remains a mystery. While electron pairing has been confirmed and is still the key requirement for the superconducting state, the coupling mechanism has not been identified. The conventional BCS theory of electron-phonon coupling is in trouble and much experimental data were presented in the sessions to dispute the electron-phonon coupling theory. Other mechanisms such as exciton (electronic polarization) and resonance valence bond theory proposed by Dr. P.W. Anderson of Princeton require further experimental data for confirmation.

- While the scientists were skeptical about a recent announcement of high transition temperature, no one is willing to rule out the possibility of developing a room temperature superconductor. This is based on the uncertainty in the mechanism.

- There seemed to be a general consensus among some physicists that the $8 billion Superconducting Super-Collider (SSC) would not be built until the characteristics of the new high T_c superconductors were understood sufficiently well to either use them for the SSC magnets or determine that their use would not be practical.

In general, the mood expressed by the physicists in the CAP meeting was cautious optimism. The significance of the discovery and the speed of the development are the two elements which impressed them most. While many scientists felt that it may be quite easy to fabricate the material, the major challenges are to study the structure and understand the mechanism so that the material can be optimized for practical use. It will require sound scientific knowledge to meet these challenges.

Submitted by:

I. Balbaa

I. Balbaa
Research Scientist
Utilization Section

F.Y. Chu
Acting Section Head
Science Section

M.A. Green
Physicist
Transmission & Special Projects Section

P. Kirkby
Physicist
Transmission & Special Projects Section

Approved by:

A.F. Baljet
Manager
Electrical Research Department

L. Mannik
Engineering Physicist
Science Section

/rdm

Canadian Association of Physicists: Outline of the Congress Held in Toronto 14-17 June 1987

There were about 600 attendees.

	Sunday 14 June 1987
Morning	All-day Council Meeting
Evening	Reception
	Monday 15 June 1987
Morning	6 Invited Paper Sessions run in parallel including: * Future Directions on Nuclear Power * Laser-Radiology-Hypothermia
Afternoon	6 Invited Paper Sessions run in parallel including: * Advanced Industrial Materials GREENAN, High Temperature Superconducting Oxides FOX, Advanced Ceramics Plenary Session: Physics and Society
Evening	Contributed Papers on High Temperature Superconductors (14 short talks about 150 attended.) Professionalism and the Natural Scientist (About 60 attended.)
	Tuesday 16 June 1987
Morning	Plenary Sessions including: * Tokamak at Varennes * Annual General Meeting
Afternoon	4 Invited Paper Sessions run in parallel including: * A Review of the Antarctic and Arctic Ozone Holes
Evening	Banquet at Hart House, After Dinner Address: Polanyi
	Wednesday 17 June 1987
Morning	6 Invited Paper Sessions run in parallel including: * High Temperature Superconductivity (About 400 attended.) CARBOTTE, Review of Evidence for an Electron-Phonon Mechanism in Conventional Superconductors BATLOGG, Oxide Superconductors, ("wire" form shown briefly) CRABTREE, Unusual Properties of Copper Oxide Superconductors ANDERSON, Resonating Valence Bond Theory of High T_c Superconductivity *Communications Device Technology
Afternoon	3 Invited Paper Sessions run in parallel including: * Epitaxial Growth of Semiconductors Contributed Papers included: *Electronic Properties of Semiconductors: Theory
Evening	Council Meeting

J.J. Judah, P. Kirkby and A.C. McMillan of Ontario Hydro organized parts of the Congress.

APPENDIX 2

Summary of Invited Papers on High Tc Superconductor

J.P. Carbotte - McMaster University - *"Review of Evidence for an Electron-Phonon Mechanism in Superconductors"*

Carbotte gave a comprehensive review of the experimental data and how the data is used to develop a model for superconductivity. All models start with the assumption of electron pairing, but the mechanism of pairing is the central issue. The BCS theory's electron-phonon interaction may not be able to explain the experimental findings.

The specific heat measurement $\Delta/\gamma Tc$ is not in favour of the BCS theory. The far infrared measurement of $2\Delta/kTc$ is also not in favour. The tunnelling data is in question. The isotope effect (ie the change of Tc by substituting O^{18} in the O^{16} site) also is against the electron-phonon mechanism.

The alternative mechanism for binding the electron is the electron-exciton (excited state electron) mechanism. A simple picture of an exciton is the polarization of the core electron by the free electron carrier. The electronic polarization will couple the two electrons together to form a pair. Cabotte cited one piece of experimental evidence from McMaster that an exciton was observed (in addition to the phonon) in the far infrared radiation absorption/reflectance measurement. The observation of a large peak at the 1000 cm^{-1} region in the optical conductivity measurement indicates the presence of electronic excitation. The lack of such a peak in a dead sample is further evidence of the presence of exciton.

Carbotte summed up the present understanding of superconductivity mechanisms by proposing a combination of electron-exciton and electron-phonon model. He cited the paper by W. Weber who calculated the phonon spectral density as evidence that the electron-phonon theory is not completely dead. Coupling energy at the phonon frequency is 8 meV while at exciton frequency it is 500 meV. The high coupling energy may lead to high Tc. (Prepared by F.Y. Chu.)

APPENDIX 2 (cont'd)

B. Batlogg - AT&T Bell Laboratories - *"Oxide Superconductors"*

This presentation dealt mainly with measurements of the isotope effect in $EuBa_2Cu_3O_7$. This was preceded by some discussion of the structural aspects of the copper oxide high Tc superconductors. These materials are essentially oxygen deficient perovskites in which the central rare earth atom is relatively unimportant. In fact every rare earth except Ce has been found to give a superconductor with Tc ~90 K. The superconductivity takes place in the copper oxide sublattice which consists of layers and chains of CuO.

In the experiments dealing with the isotope effect a sample of $EuBa_2Cu_3O_7$ was split into two parts, one of which had 75% of its oxygen -16 replaced by oxygen -18 through exchange at elevated temperatures. The Raman spectra of the two samples were measured at 77 K and the four peaks between 400 and 650 cm^{-1} had their frequency shifted by ~4%, as expected from the oxygen mass change. This also confirmed that the observed vibrations involved the motion of oxygen atoms. Based on the BCS theory such a shift in the phonon frequencies should have produced a difference in Tc of nearly 4 K in the two samples. Experimentally Tc as determined by both resistive and Meissner-effect measurements for the two samples differed by less than 1/20 of a degree. Batlogg agreed with Carbotte that one would have to postulate an unreasonably large value of the renormalized Coulomb interaction μ^* in order to explain the absence of an isotope effect within the framework of the traditional BCS electron-phonon theory. However, no isotope effect is expected for a purely electronic mechanism such as the electron-exciton model.

Batlogg summarized the properties of $YBa_2Cu_3O_7$ system as follows:

Tc	=	92.5 K
ρ_{300}	=	300 - 700 μΩ-cm
ρ_{95}	=	200 - 250 μΩ-cm
Jc	>	1100 A/cm^2
Dominate charge carrier	P type	
Thermodynamic critical field	10±2 kOe	

In answer to a question from the audience, Batlogg said that he knew of no convincing evidence for superconductivity at temperatures above 200 K and he wasn't really interested in appearing in the New York Times so he wouldn't comment further. (Prepared by L. Mannik.)

APPENDIX 2 (cont'd)

G.W. Crabtree - Argonne National Laboratory - *"Unusual Properties of Copper Oxide Superconductors"*

This presentation covered several aspects of fundamental studies of the $YBa_2Cu_3O_{7-\delta}$ superconductor, beginning with an investigation of the effect of replacing some of the Ba atoms with the smaller Sr atom. Although they expected little or no effect as a result of this substitution, the Argonne researchers found a decrease in Tc with increasing Sr content, eg $YBa_{2-x}Sr_xCu_3O_{7-\delta}$ gave a Tc of 87 K with x = 0.2 and 76 K with x = 1.5. They surmise that the smaller size of the Sr^{2+} ion (1.27 A compared to 1.5 A for Ba^{2+}) results in fewer oxygen atoms being coordinated with the Sr and that with increasing Sr concentrations oxygen atoms are removed from the chain positions (O1 position).

The second part of the presentation dealt with experiments in which samples were heated up to various temperatures below the orthorhombic to tetragonal phase transition at 750°C. The oxygen content was frozen by quenching samples in liquid N_2 and Tc was measured as a function of oxygen content. It was found that Tc could be depressed at will by varying the quench temperature which in turn changed the oxygen depletion at the 04 site. For "dead" $YBa_2Cu_3O_x$ superconductor (Tc~OK), x was ~6.5 while for Tc = 90 K material x was 6.85. The Cu1 - 04 distance was also different in the two cases, 1.85 A for Tc = 90 K and 1.815A for Tc ~ OK. The conclusion was that the one dimensional copper oxide chains play an important role in superconductivity. In the tetragonal phase where there is no superconductivity these chains are completely absent.

Finally, Crabtree discussed measurements of the critical current density as a function of temperature for both single and poly-crystals of the $YBa_2Cu_3O_{7-\delta}$ material. J.Z. Liu at Argonne has apparently developed a technique for growing single crystals as large as 0.3 mm x 0.3 mm x 0.3 mm. For a single crystal the critical current density was 1.4×10^6 A/cm^2 at 5 K and this dropped to 1.1×10^5 at 45 K and 1.1×10^4 at 77 K. The corresponding values for a polycrystalline sample were 1.4×10^4 A/cm^2 at 5K, 6.6×10^2 at 45 K and 2.3×10^2 at 77 K. The reduction in critical current with increasing temperature appears to be an intrinsic feature of these superconductors which means that for practical applications where a current density of ~10^6A/cm^2 at 77 K is desirable, it would be necessary to start with a current density of ~10^3 A/cm^2 at 5 K for a polycrystalline material. (Prepared by L. Mannik.)

APPENDIX 3

Invited Paper: Advanced Industrial Materials

High Temperature Superconducting Oxides, J.E. Greedan, McMaster University

Review of HTSC in ceramic materials

1975	$LiTi_2O_4$	
	$Ba(PB_{1-x}Bi_x)O_3$	Tc = 13 K
1986	$La_{1.8}Ba_{0.2}CuO_4$	Tc = 29 K
	$La_{1.85}Sr_{0.15}CuO_{4-y}$	Tc = 36-40 K
1987	$YBa_2Cu_3O_7$	Tc = 95°K

- IBM prepared epitaxial films of 1-2-3 compound with Jc = $10^5 Acm^{-2}$
- Substitution of rare earth elements: Nd, Sm, Eu, Gd, Dy, Ho, Er, Jm, Yb and Lu, for Y have no effect on Tc.
- The critical current is sensitive to defects and mechanical properties. Jc can therefore be controlled to a large degree by the microstructure of the ceramic.
- In the $YBa_2Cu_3O_x$ compound, the oxygen content (X) plays a significant role in the superconductivity of the material: below x = 6.3, superconductivity is not observed: At x=7, Tc = 95°K
- The superconductive crystal structure is orthorombic. A tetragonal, non superconducting phase is obtained when quenching the ceramic from temperatures above 600°C to room temperature. The transformation from tetragonal to orthorombic seem to be related to the oxygen content.

Monday Evening Sessions (contributed papers)

1. Magnetic Properties of High-Tc Oxide Superconductor F.S. Razavi, F.P. Koffyberg and B. Mitrovic, Brock University.

   Magnetization as a function of magnetic field was measured experimentally for $La_{1.85}Sr_{0.15}CuO_4$ and $YBa_2Cu_3O_7$ compounds.

   Results indicate that the new HTSC are type II superconductors. Considerable magnetic flux trapping was observed indicating ceramic consisted of two phases: a superconducting phase and a non-superconducting phase.

McMaster University, Department of Physics presented three papers:

2. Eliashberg Theory and the High Tc Oxides.

3. Thermodynamic, Electromagnetic and other properties of $La_{1.85}Sr_{0.15}CuO_4$

4. Specific Heat Jump in the Very Strong Coupling Limit and the High Tc Oxides.

In these three presentations, the McMaster Physics group attempted to review the criteria for strong coupling interactions in superconductivity. Criteria such as the value of $2\Delta(0)/K_BTc$, the electron-phonon coupling parameter and the size of the discontinuity in the specific heat at Tc.

Based on the preliminary experimental data available at the present time, it was concluded that the oxide superconductors are very strong coupling superconductors. However, the value of most of the parameters evaluated deviate anomalously from the classical theories of superconductivity which are based on the Eliashberg and BCS theories.

The investigators thus suggest that a second mechanism for superconductivity exists together with the electron-phonon coupling. Very strong exciton coupling is suggested to be the main cause of superconductivity in this new class of materials. Evidence of the existence of excitons was based upon infrared absorption measurements.

5. Magnetic Penetration Depth and Flux-Pinning Effects in High-Tc Superconductor $La_{1.85}Sr_{0.15}CuO_4$

AT&T Bell Labs
University of Saskatchewan
University of British Columbia

Muon spin relaxation technique has been used to determine the magnetic penetration depth λ. At 10°K λ-2600A. It was found that λ does not follow the "classic" superconductivity relation:

$$\lambda(t) = \lambda(0)/(1-t^4)^{1/2}$$

(t=T/Tc) indicating the possibility that these new HTSC are a new class of superconductors.

6. Microwave Study of High-Tc Superconductivity.

M. Poiver, G. Quirion - University Sherbrooke
A.J. Freeman, K. Poeppelmeir - Northwestern University

APPENDIX 3 (cont'd)

Microwave absorption by the new superconducting oxides $La_{18}Sr_{0.2}CuO_4$ and $YBa_2Cu_3O_7$ were studied in the frequency range 9-17GHz, the temperature regime 1.5-200 K and under magnetic fields of 0-7 Tesla.

Microwave absorption was found to increase significantly at the transition temperature. The absorption curves for the two compounds differ below Tc. For the (La, Sr) compound the absorption initially decreased with increasing temperature while in the case of the (Y,Ba) compound the absorption increased with increasing temperature. Also for the (Y,Ba) compound microwave absorption increased, below Tc with decreasing oxygen content. For the composition $YBa_2Cu_3O_{7-3}$ the absorption is zero at O°K. It was also reported that the magnetic field increases the absorption below Tc.

7. The Infrared Conductivity of the High-Tc Superconductors $YBa_2Cu_3O_{7-x}$ McMaster University and University of Florida

Infrared reflectance of the 1-2-3 oxide was measured above and below Tc. Peaks at the wave numbers of 153, 191, 281, 312, 563 and 628 cm^{-1} were observed in both the superconducting and normal states. However the peak at 191 cm^{-1} increased in strength significantly below Tc. Also IR absorption was measured for two samples differing in their oxygen content. The first was a superconductor which showed an absorption peak at about 2000 cm^{-1} while the second was not a superconductor which differed only with the first material in oxygen content (ie the non superconducting material is oxygen deficient). No absorption peak was observed for this material. It was suggested that the peak at ~2000 cm^{-1} could indicate the presence of excitons which would be mainly responsible for the superconductive state.

(Prepared by I. Balbaa.)

APPENDIX 4

Monday Evening Sessions - Second Half

8. Greedan (McMaster) *Oxygen Ordering in the Crystal Structure of the 93 K Superconductor by Powder Neutron Diffraction at 298 K and 79.5 K.*

   - The higher the oxygen content, the better
     at $O_{6.2}$ Tc=0
     at O_7 Tc max. ~100 K

   - Oxygen moves in and out from the site by re-oxidation.

9. Timusk (McMaster) *The Infrared Conductivity of the High Tc Superconductor* $La_{1.85}$ $SR_{0.15}$ CuO_4.

   - IR conductivity measurements to determine α $(\Omega\text{-cm})^{-1}$

   - Observe phonon, weak coupling SC at $2\Delta/KTc \approx 3.5$

   - Observe strong electronic feature at 0.44 eV.

10. E.W. Fenton (NRC) *The Role of Spin Density Waves in HTSC.*

    - Could spin waves be a coupling mechanism to explain HTSC. Theoretical paper, needs experimental evidence.

11. J. Greedan, (McMaster), Koffyberg (Brock), Buyers (AECL) *Neutron Diffraction in the HTSC* $La_{1.15}Sr_{0.85}CuO_4$

    - Use neutron source at Whiteshell for neutron diffraction determination of the crystal structure. Orthorhombic structure.

12. M. Mohan (McGill) *Spin-Singlet D-Waves Hole Pairing in New High Tc Superconductors*

    - Use spin fluctuation to explain the formation of pairs (hole), estimate from theory Tc ~120 K.

    - Comparison with Anderson's Resonance Valence Bond Theory.

APPENDIX 4 (cont'd)

13. J. Jung (Alberta) *Superconductivity in the System* $(Al_xY_{1-x})Ba_2Cu_3C_{6.5+8}$.

    - Substitute aluminum in the Yttrium site
    - Change of Tc (90 K -> 50 K) when aluminum concentration increases.

14. Shih & Qui (McGill, Electrical Engineering) *Sample preparation technique*

    - Care in preparing the samples, in particular, the pressure applied in pressing etc, and the effects on Tc.
    - Higher pressure, increase in Tc.

(Prepared by F.Y. Chu.)

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